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WATERTON LAKES
WATER QUALITY ASSESSMENT

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PREPARED FOR CANADIAN PARK SERVICE

BY

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MANAGEMENT PERSPECTIVE

The quality of water in the Waterton lakes continues to be excellent, with no deterioration since the 1970s. Bacteria levels in the vicinity of the townsite have declined in response to improvement of the sewage treatment facility and relocation of the effluent discharge. The information provided by this cooperative Canadian Parks Service - Water Quality Branch study lays the ground work for the development and implementation of water quality objectives for Waterton lakes. The water quality objectives would be part of the long-term water management plan that would contribute to the maintenance of the high quality of water in the Park. The water management plan could also provide for the development of a water resources public information document for the Park using knowledge from this study. Water quality data generated by the Water Quality Branch routine monitoring of the Waterton River at Highway 6 provides an indication of water quality at the international boundary and throughout the Waterton lakes. Due to the influence of Crooked Creek, however, it is not indicative of the water quality in Waterton River crossing the Park boundary during low flow conditions.

ABSTRACT/RÉSUMÉ

During the summer of 1988 a water quality study of the Waterton Lakes in Waterton Lakes National Park was undertaken by the Water Quality Branch of Environment Canada. The objectives of this study were to provide additional information on the quality of water in the lakes and to compare the new data with data collected in the 1970s and to examine the water quality in the Waterton River between Lower Waterton Lake and the Park boundary. The information obtain was to assist the Canadian Parks Service in the management of the surface water quality in the Park. The study included the collection of water samples for nutrient, major ion, metal, bacteriological and physical analysis. The results of these analyses show that the quality of the lakes remains very high and has not changed significantly since similar work was conducted in the 1970s. Samples collected in the near-shore waters around the Waterton townsite indicate the quality has improved since the 1970s. This improvement can probably be attributed to the improvements in sewage treatment and disposal undertaken by Canadian Parks Service in the intervening years. Samples collected from the Waterton River suggest that the routine monitoring of the river provides a good indication of the water quality in the Waterton lakes. However, the inflow of Crooked Creek below the monitoring site reduces the ability of the routine monitoring program to describe the quality of water leaving the Park in the Waterton River.

Au cours de l'été de 1988, la Direction de la qualité des eaux d'Environnement Canada a mené une étude dans le parc national des lacs Waterton. Cette étude avait pour objectifs de recueillir des données supplémentaires sur la qualité de l'eau des lacs, de comparer les nouvelles données avec celles recueillies au cours des annees 1970 et d'analyser la qualité de l'eau de la rivière Waterton, entre le lac Waterton et la frontière du parc. Les données obtenues aideront le Service canadien des parcs à contrôler la qualité des eaux de surface dans ce parc. Dans le cadre de cette étude, on a recueilli des échantillons d'eau afin de procéder à une analyse physique et bactériologique, et de mesurer la teneur en éléments nutritifs, en ions majeurs et an métaux. Les résultats obtenus révèlent que la qualité de l'eau demeure très élevée et n'a pas subi de changement important depuis les années 1970, lorsqu'on avait mené une étude semblable. L'analyse d'échantillons preleves a proximité de la rive près du village de Waterton révèle que la qualité de l'eau s'est améliorée depuis les années 1970. Ces résultats sont probablement attribuables aux améliorations apportées par le Service canadien des parcs au système de traitement et d'élimination des eaux usées. L'analyse d'échantillons prélevés dans la rivière Waterton laisse supposer qu'un contrôle régulier de ce cours d'eau donne une bonne indication de la qualité de l'eau des lacs Waterton. Toutefois, l'eau provenant du ruisseau Crooked, situé en aval du lieu de prélèvement, nuit à l'exactitude des données du programme de contrôle régulier, qui vise à évaluer la qualité de l'eau s'écoulant en dehors du parc dans la rivière Waterton.

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1.0 INTRODUCTION

During the mid 1970s the water quality of Waterton Lake and tributary streams in Waterton Lakes National Park was examined by the Water Quality Branch of Environment Canada to provide information to Parks Canada on existing water quality and to identify any problem areas (Water Quality Branch, 1974; Block and Gummer, 1976). This work showed that for the most part the water was of excellent quality reflecting the pristine mountain environment. However, the area around the Waterton townsite was identified as an area of possible concern due to nutrient and bacterial influences from the townsite, particularly the sewage discharge to Waterton Lake via Cameron Creek. Since then, Canadian Parks Service has taken action to remedy this situation by improving its sewage treatment facility and relocating the discharge to the Waterton River.

In 1987, Canadian Parks Service indicated that they would like to have a water quality assessment conducted in the Park and in particular in the Waterton lakes. The Water Quality Branch agreed to conduct a water quality study of Waterton Lakes and undertook a study during the summer of 1988. This study was to provide information and advice to Canadian Parks Service for the management of the water quality of surface waters in Waterton Lakes National Park.

Two objectives were established for this study. One was to provide additional information on the quality of water in

Waterton lakes and to compare the new data with data collected in the 1970s. This was accomplished by sampling at the same sites as in the 1970s and by conducting a near shore sampling program in the vicinity of the Waterton townsite. The second objective was to examine the water quality in the Waterton River between Lower Waterton Lake and the Park boundary. This assessment was required to address questions regarding the ability of the Water Quality Branch routine monitoring program, conducted on the Waterton River, to fulfill a number of functions, including: providing information on water quality conditions at the International Boundary on Upper WAterton Lake, at the Park boundary, and in the Waterton lakes in general.

Three additional objectives and/or activities were also set out to be undertaken in subsequent years. These were:

1. The development of water quality objectives, for use by Canadian Parks Service in the management of water resource within the Park through an evaluation of all available data in consultation with appropriate agencies (Canadian Parks Service, Alberta Environment) and downstream water users.

2. The preparation of a management plan for the implementation of water quality objectives within Waterton Lakes National Park.

3. To assist in the development of a public information plan for water quality in Waterton Lakes National Park.

1.1 Study Area

Waterton Lakes National Park is situated on the eastern edge of the Rocky Mountains of southwestern Alberta. The Park borders on Glacier National Park in Montana to the south and British Columbia to the west. The Waterton Lakes are the major water bodies within the Park. The upper lake is shared by Glacier and Waterton Lakes National parks as it is traversed by the International Boundary.

Waterton Lakes consists of three water bodies, the Upper, Middle and Lower Waterton lakes. The Upper and Middle Waterton lakes are joined by a shallow narrows known as the Bosporus near the Waterton townsite. Middle Waterton Lake is drained by a stream known as the Dardanelles into Lower Waterton Lake from which the Waterton River flows (Figure 1).

The two upper lakes lie between the Clarke Range to the west and Lewis Range to the east. The lower lake is situated in the prairie region of the Park. Morphometric data for the lakes are presented in Table 1. The lake basins were produced by erosion of alpine glaciers. The geology of the mountainous region is sedimentary quartzites, metargillites, limestone and dolomites of late Precambrian age. The rock formation in the Bosporus is composed of resistant strata of bedded dolomites of the Altyn formation (Cuerrier and Schultz, 1957). The

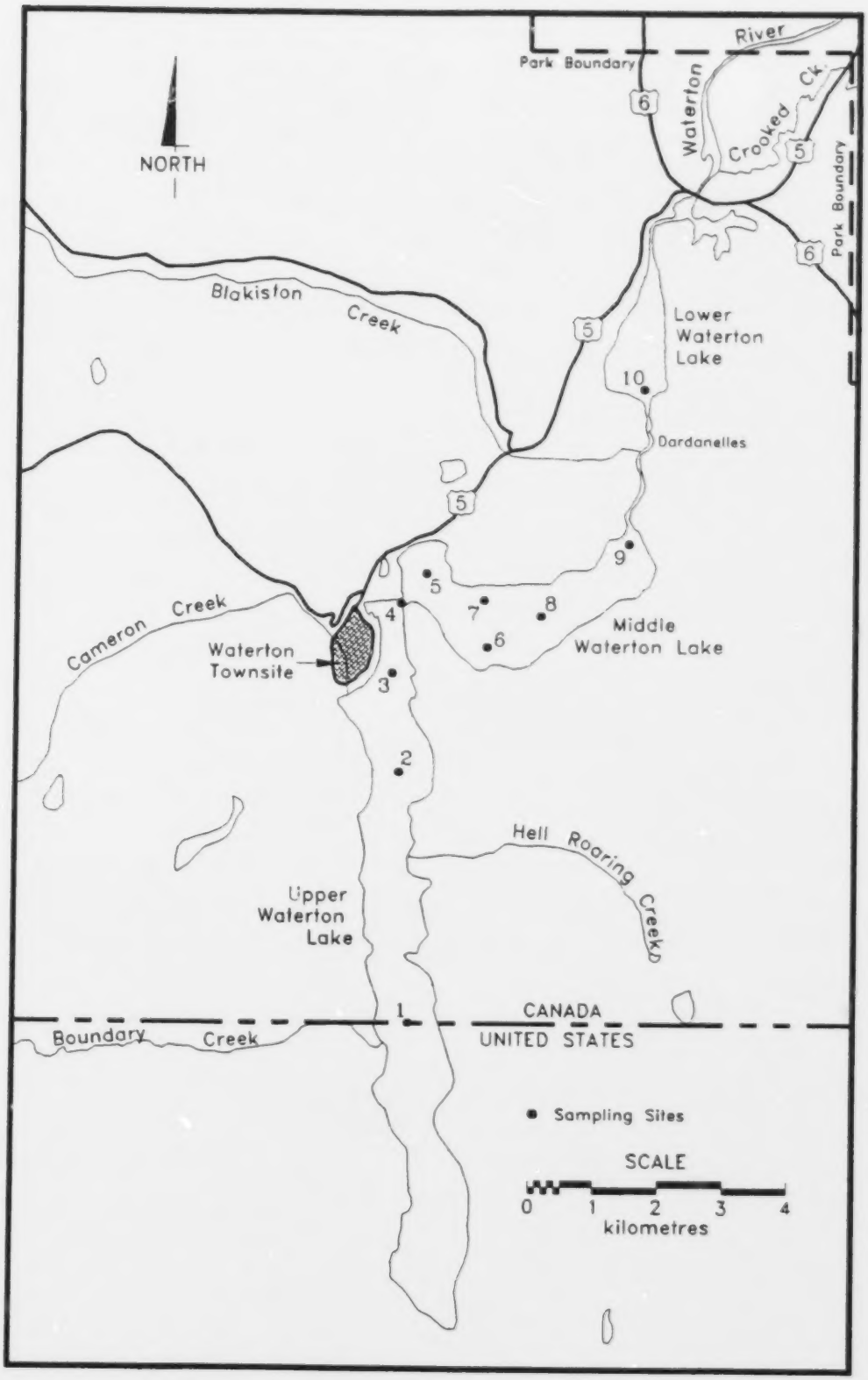

FIGURE 1. Map of Study Area Showing Mid Lake Sampling Sites.

lower reaches of Middle Waterton Lake and Lower Waterton Lake are located in the delta created by Blakiston and Sofa creeks. The surrounding prairie land consists of eskers and moraines composed of silt, sand and gravel, the most important of which are the flat-topped Kame terraces (Surveys and Mapping Branch, 1973).

Inflow to the lakes is from snow-melt water, surface drainage and direct precipitation. The upper lake is fed by Cameron, Bertha, West Boundary, Street, Kootenai and Hell Roaring creeks and numerous intermittent streams. The lower lakes are fed by six intermittent streams (Krishnaswami, 1968).

Table 1. Morphometric Data for the Waterton Lakes.

Parameter	Upper Waterton Lake	Middle Waterton Lake	Lower Waterton Lake
Elevation (m)	1278.3	1278.0	1276.5
Length (km)	11.1	3.8	2.2
Surface Area (ha)	941.	429.	143.
Volume (cu. dam)	645200.	74200.	3970.
Max. Depth (m)	135.3	27.4	7.3
Mean Depth (m)	68.6	17.3	2.8

(Data taken from Anderson et al., 1976)

2.0 METHODS

Two surveys of the Waterton Lakes were conducted in 1988 (August 15 to 19 and September 19 to 23) to examine the water quality relative to that found in the mid 1970s. Each survey consisted of sampling at 10 sites (Table 2) which were similar to the sites sampled during the mid-1970s (Figure 1). Samples were collected from two depths, 5 and 20 or 25 metres where there was sufficent water depth. A near-shore survey of 10 sites (Table 2) in the immediate vicinity of the Waterton townsite was conducted in August, 1988 to identify possible impact from the townsite. The locations of these near shore sites are shown on Figure 2. Samples were analyzed for a variety of water quality variables including physical, nutrient, major ion and bacteriological parameters as shown in Table 3. In addition, samples for metal analysis were collected from the mid-lake sites during the August survey.

Samples were collected by Water Quality Branch and Canadian Parks Service personnel using an acrylic alpha bottle. Samples were immediately poured into their appropriate sample containers and preserved as decribed in the Water Quality Branch field methods manual (1983). Samples for dissolved parameters were returned to the field lab where they were filtered and preserved as required. Field physical measurements were also completed at this time. Bacterial sample analyses were conducted in the field lab using the membrane filtration techniques described by APHA (1980). All

Table 2. Decription of Sampling Sites.

Site Number		Sampling Depth (metres)
	Waterton Lake, Mid Lake Sites	
1	Waterton Lake at the International Boundary	5, 25
2	Waterton Lake South of Waterton	5, 25
3	Waterton Lake at Waterton	5, 25
4	Waterton Lake at Bosporus	5, 15
5	Middle Waterton Lake East-northeast of Linnet Lake	5, 20
6	Middle Waterton Lake South of Catholic Youth Camp south shore	5
7	Middle Waterton Lake South of Catholic Youth Camp north shore	5
8	Middle Waterton Lake Southeast of Catholic Youth Camp	5, 20
9	Waterton Lake above the Dardenelles	1
10	Lower Waterton Lake at mouth of Dardanelles	0.5
	Waterton Lake, Near Shore Sites	
11	Waterton Lake at Cameron Creek Outlet	1
12	Waterton Lake off Campground near Double Kitchen	1
13	Waterton Lake off Beach in Front of First Cabin	1
14	Waterton Lake off Beach by Peace Park Pavilion	1
15	Waterton Lake at Marina	1
16	Waterton Lake off Swimming Area in Emerald Bay	1
17	Waterton Lake at Warden's Dock	1
18	Waterton Lake in Emerald Bay by Camp Kitchen	1
19	Waterton Lake at Dock in Driftwood Bay	1
20	Waterton Lake at North End of Driftwood Bay	1
	Waterton River Site Evaluation Sites	
21	Waterton River at Highway 6 Bridge	Mid Depth
22	Waterton River above Crooked Creek	Mid Depth
23	Waterton River below Crooked Creek	Mid Depth
24	Crooked Creek above Waterton River	Mid Depth
25	Crooked Creek at Highway 5	Mid Depth

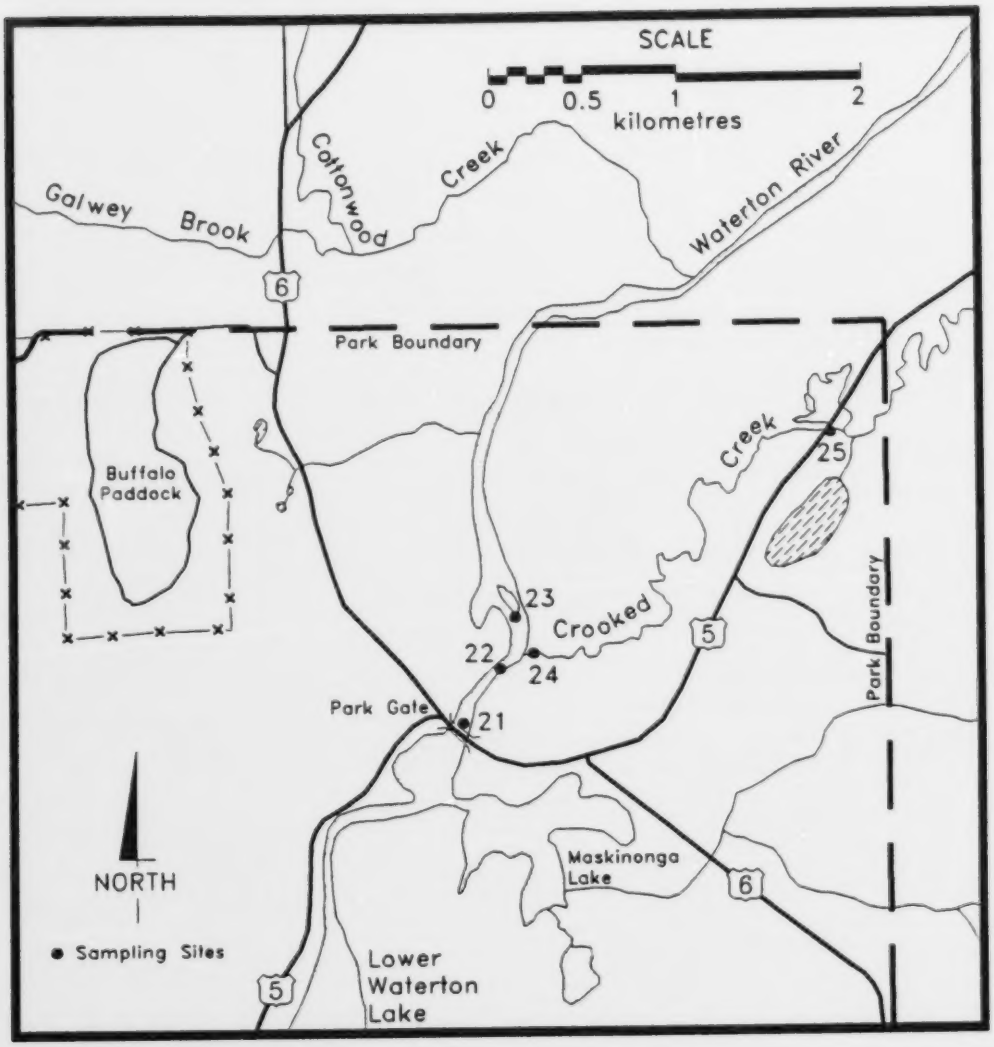

FIGURE 3. Map of Waterton River and Crooked Creek Sampling Sites.

Table 3. Water Quality Parameters Analyzed.

Parameter Groups	Mid Lake Program	Near Shore Program	Waterton R. Program
Field Physicals:	All Sites	All Sites	All Sites
Conductance			
pH			
Turbidity			
Dissolved Oxygen			
Temperature			
Secchi Depth			
Lab Physicals:	All Sites	All Sites	All Sites
Conductance			
pH			
Turbidity			
Temperature			
Colour			
Non filterable residue			
Nutrients:	All Sites	All Sites	Select Sites
* Total Phosphorus			
Dissolved Phosphorus			
* Dissolved Nitrogen			
* Particulate Nitrogen			
* Nitrite/Nitrate			
Particulate Organic Carbon			
Dissolved Organic Carbon			
Major Ions:	All Sites	All Sites	Select Sites
Total Alkalinity			
Phenol Alkalinity			
Calcium			
Magnesium			
Fluoride			
Potassium			
Sodium			
Chloride			
Silica			
Sulphate			
Bacteria:	All Sites	All Sites	All Sites
Total Coliform			
Fecal Coliform			
Fecal Streptococci			
Chlorophyll a	All Sites	All Sites	-----
Metals/Trace Elements:	All Sites August Survey only	-----	-----
Cadmium			
Cobalt			
Nickel			
Copper			
Lead			
Zinc			
Barium			
Vanadium			
Mercury			
Dissolved Aluminum			
Dissolved Arsenic			
Dissolved Selenium			
Dissolved Iron			
Dissolved Manganese			

* nutrients analyzed as part of the Waterton River site evaluation

field preparation of samples was completed within six hours of collection of the samples.

Waterton River site evaluation sampling was conducted at five sites, three on Waterton River and two on Crooked Creek (Figure 3, Table 2). Samples were collected directly into appropriate containers from mid depth while wading at approximately mid stream. Samples were analyzed for physical, bacterial, nutrient and major ion parameters. Sample filtration, preservation and bacterial and field physical analyses were conducted in the field lab within six hours of collection.

Samples were subsequently shipped to Water Quality Branch analytical laboratories in Saskatoon, Saskatchewan and Burlington, Ontario where chemical analyses were conducted using routine analytical methods (Water Quality Branch, 1979).

3.0 RESULTS AND DISCUSSION

3.1 Waterton Lakes Mid-Lakes Program

Samples from the mid-lake sites (Table 2, Sites 1 to 10) suggest there was little or no difference between samples collected at five metres and at greater depths (15 to 25 m), indicating that a thermocline did not from between the two sampling depths and that the surface water to 25 metres was mixed. In other years, a thermocline has occur in Upper Waterton Lake between 15 and 25 metres (Anderson et al., 1976;

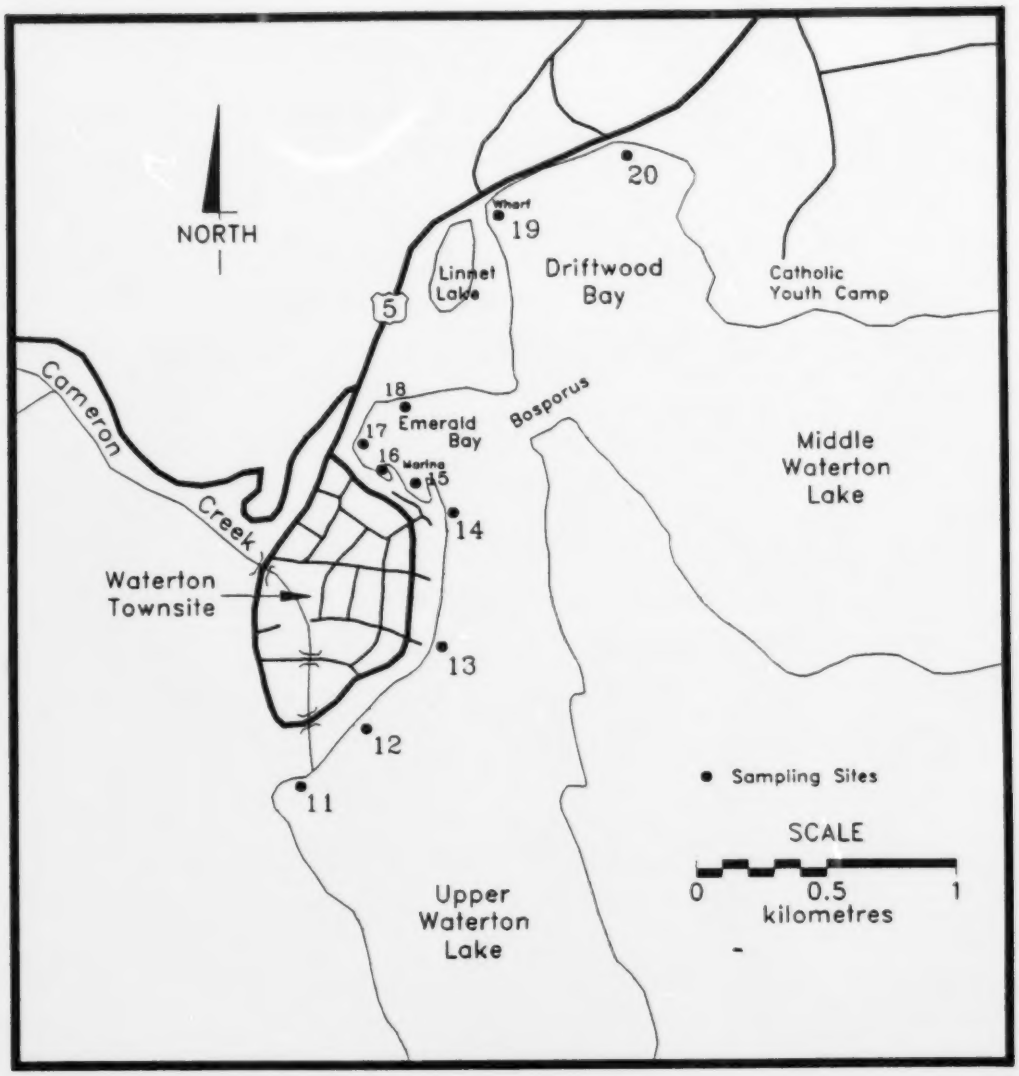

FIGURE 2. Map Showing Near Shore Sampling Sites.

Krishnaswami, 1967). However, Rawson (1942), suggested the thermocline occurred between 25 and 35 metres in 1937, which was likely the case in 1988. Data collected by the Water Quality Branch in the early 1970s also did not show the formation of a thermocline above 25 metres. As a result of the water being mixed, subsequent discussion of the data will not differentiate between samples from various depths.

3.1.1 Physical Parameters

The dissolved oxygen concentration was relatively consistent throughout the lakes (Table 4), ranging from 8.4 to 9.4 mg/L. This represents an oxygen level near saturation with water temperatures ranging from 8 to 17.5 degrees Celcius. Secchi disc readings ranged from 2.5 to 8 m with the higher reading occurring in Upper Waterton Lake (sites 1 to 4). This high transparency is also reflected in the non-filterable residue (NFR), turbidity and colour data. The colour in all samples was below the detection level of 5 relative light units. NFR was below the detection level of 1 mg/L at the upper lake sites and only slightly higher (maximum 4 mg/L) in the Middle and Lower Waterton lakes (sites 5 to 10). Turbidity displayed a pattern similar to NFR and displayed a slight increase from the upper to the lower lake sites. NFR and turbidity also increased by about a factor of two in the Middle and Lower Waterton lakes from August to September.

Table 4. Biological and Physical Data for the Mid Lake Sites, 1988.

		Parameters and Method Codes												
Site No.	Collection Date	Depth 97251F meters	Secchi meters	Colour 02021L r. unit	NFR 10401L	Cond 02041L usie/cm	Temp 02061F deg C	DO 08101W	Turb 02073L NTU	pH 10301L pH Unit	Ch-a 06717G	TC (MF) 36002F -----	FC (MF) 36012F #/100 mL	FS (MF) 36103F ------
1	08/16	5.0	8.	< 5.	< 1.0	159.	14.5	9.1	0.24	8.04	0.001	< 2.	< 2.	< 2.
1	08/16	25.0		< 5.	< 1.0	144.	14.5	9.2	0.76	8.07	0.001	< 2.	2.	10.
1	09/20	5.0	6.	< 5.	< 1.0	138.	11.1	9.4	0.26	8.23	0.001	NV	10.	< 2.
1	09/20	25.0		< 5.	< 1.0	138.	11.2	9.4	0.21	8.22	0.001	< 2.	< 2.	< 2.
2	08/16	5.0	7.	< 5.	< 1.0	146.	14.6	9.1	0.27	8.08	0.001	< 2.	< 2.	< 2.
2	08/16	25.0		< 5.	< 1.0	136.	12.9	9.4	0.27	8.16	0.001	< 2.	< 2.	< 2.
2	09/20	5.0	6.	< 5.	< 1.0	137.	11.3	9.2	0.26	8.22	0.001	< 2.	< 2.	10.
2	09/20	25.0		< 5.	< 1.0	138.	11.4	9.3	0.21	8.19	0.001	< 2.	< 2.	2.
3	08/16	5.0	7.	< 5.	< 1.0	135.		9.0	0.41	8.14	0.001	4.	< 2.	2.
3	08/16	25.0		< 5.	< 1.0	137.	12.5	9.4	0.37	8.09	0.001	< 2.	< 2.	< 2.
3	09/20	5.0	7.	< 5.	< 1.0	138.	11.5	9.2	0.24	8.24	0.001	NV	10.	< 2.
3	09/20	25.0		< 5.	< 1.0	148.	11.3	9.5	0.24	8.22	0.001	< 2.	< 2.	16.
4	08/16	5.0	6.	< 5.	< 1.0	144.	15.8	9.2	0.28	8.17	0.001	2.	< 2.	< 2.
4	08/16	15.0		< 5.	2.0	145.	15.	9.4	0.66	8.13	0.001	4.	< 2.	4.
4	09/20	5.0	8.	< 5.	< 1.0	138.	11.6	9.4	0.24	8.20	0.002	NV	10.	< 2.
4	09/20	15.0		< 5.	< 1.0	138.	11.7	9.2	0.25	8.20	0.001	2.	2.	425.
5	08/16	5.0	5.	< 5.	1.2	136.	16.7	8.6	0.59	8.14	0.001	< 2.	< 2.	< 2.
5	08/16	20.0		< 5.	1.0	144.	17.5	9.0	0.46	8.19	0.001	< 2.	< 2.	< 2.
5	09/20	5.0	3.3	< 5.	2.6	148.	12.8	9.4	1.36	8.18	0.004	< 2.	< 2.	16.
5	09/20	16.0		< 5.	3.0	148.	12.8	9.0	1.58	8.25	0.006	< 2.	< 2.	< 2.
6	08/16	5.0	4.	< 5.	1.4	137.	16.2	8.7	0.57	8.18	0.002	4.	< 2.	< 2.
6	09/20	5.0	4.	< 5.	2.6	148.	12.5	9.2	1.49	8.23	0.005	NV	6.	15.
7	08/16	5.0	4.	< 5.	1.4	136.	17.4	8.8	0.47	8.19	0.001	< 2.	< 2.	< 2.
7	09/20	5.0	4.	< 5.	3.0	148.	13.0	9.2	1.70	8.24	0.005	NV	4.	11.
8	08/16	5.0	4.	< 5.	1.2	137.	16.5	9.5	0.53	8.17	0.002	10.	< 2.	10.
8	08/16	20.0		< 5.	1.4	137.	16.6	9.0	0.42	8.11	0.001	< 2.	< 2.	< 2.
8	09/20	5.0	2.5	< 5.	2.6	148.	12.8	9.2	1.69	8.30	0.005	< 2.	< 2.	2.
8	09/20	20.0		< 5.	4.0	148.	12.7	8.9	2.3	8.23	0.006	9.	< 2.	15.
9	08/16	1.0	> 4.	< 5.	< 1.0	144.	17.	9.3	0.66	8.06	0.001	2.	< 2.	2.
9	09/20	1.0	2.5	< 5.	2.2	148.	13.2	9.1	1.04	8.29	0.004	< 2.	< 2.	< 2.
10	08/18	0.5		< 5.	1.2	144.	14.	8.4	0.55	8.04	0.001	< 2.	4.	2.
10	09/21	0.5		< 5.	3.2	172.	8.0	9.3	1.52	8.11	0.004	21.	8.	12.

Data in mg/L unless stated otherwise.

Comparison of the field and physical data collected in 1988 with the data collected during the mid 1970s (Block and Gummer, 1976; Water Quality Branch, 1974) show there has been no significant change in these parameters. Figure 4 shows box and whisker plots of the 1970s specific conductance and turbidity data with the 1988 data over plotted. These graphs suggest that no significant change has occurred in these parameters in the intervening years. The 1988 turbidity data all fall within the range of the earlier data and are for the most part at the lower end of the range. Specific conductance data on the other hand are at the higher end of the range and at some sites above the range of the earlier results, suggesting a possible increase in specific conductance. However, this apparent increase is not statistically significant and examination of the major ion data in a subsequent section of this report suggest there is no difference in the major ions levels in the lakes. The 1988 physical data are also similar to values found in the thirties, early fifties and late sixties (Rawson, 1942; Cuerrier and Schultz, 1957; Krishnaswami, 1968).

3.1.2 Bacteriological Variables

Total and fecal coliform and fecal Streptococci are used as indicators of potential water contamination by pathogenic organisms of fecal origin. The coliform group is made up of a number of bacteria including Klebsiella, Escherichia, Erwinia, Serratia, and Enterobacteria which are associated with the

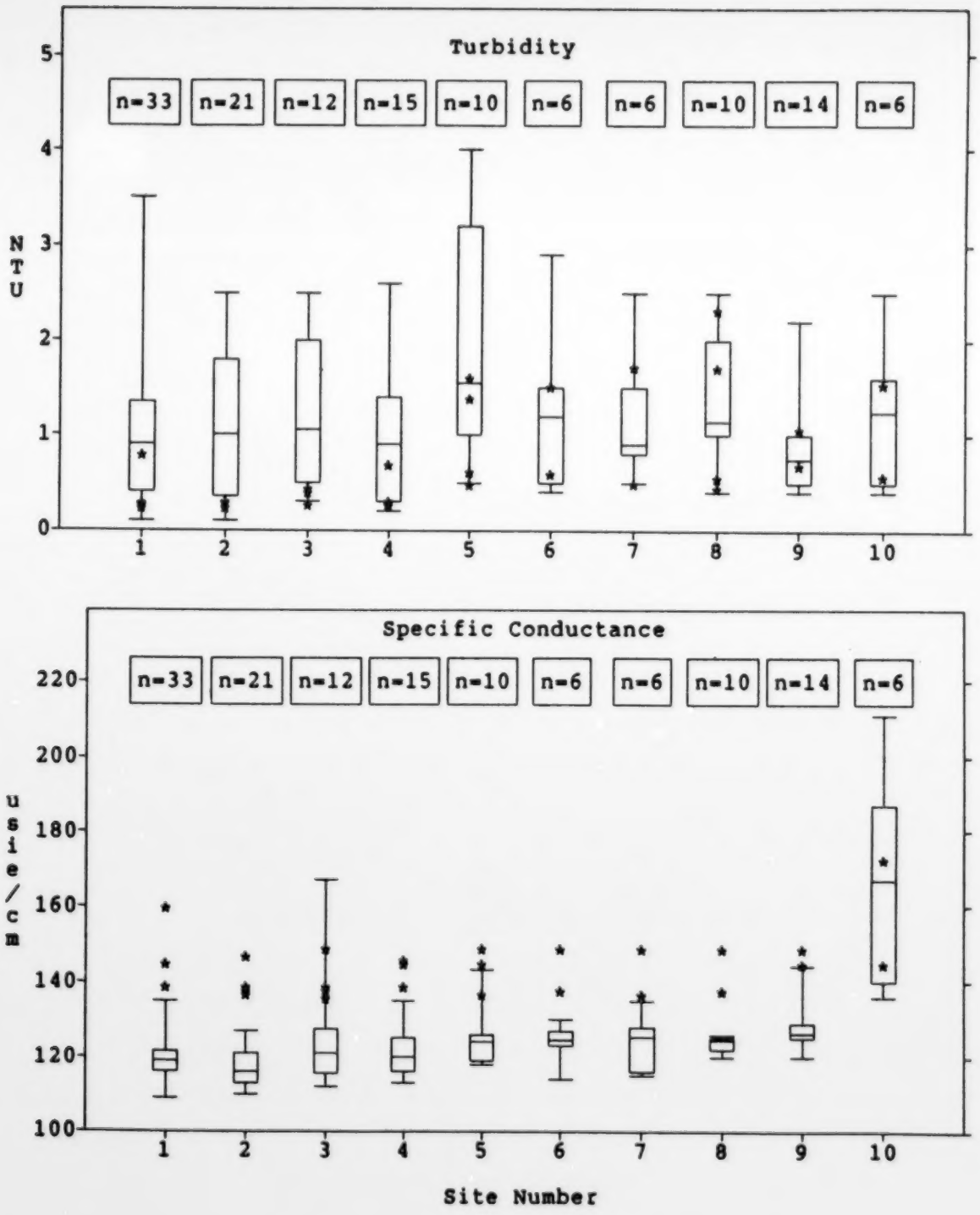

Figure 4. Box and Whisker Plots of Historical Turbidity and Specific Conductance Data with 1988 Data Overplotted. Where the box represents the quartiles, the line inside the box is the mean and the lines outside the box represent the range.

feces of warm-blooded animals and with soil. Fecal coliform have been proven to be a better estimate of sanitary pollution than total coliform because fecal coliform bacteria are restricted to the intestinal tract of warm-blooded animals. Fecal Streptococci are more resistant to natural and man-made purification processes than are the coliform group. Therefore, fecal Streptococci may be a better indicator of fecal pollution at points distant from the source where fecal coliforms are no longer present. Fecal coliform to fecal Streptococcus ratios are often used to indicate the origin of fecal pollution. Ratios greater than 4 indicate pollution derived from humans and ratios less than 0.7 indicates pollution derived from livestock or poultry. Ratios between 0.7 and 4 suggest pollution from mixed sources (APHA, 1980). However, when counts are less than ideal (less than 20 colonies per plate) interpretation of these ratios is difficult.

The bacteria results from the mid-lake sites are presented in Table 4. These results show there was little or no bacterial pollution of the lakes. The majority of samples did not produce any bacterial colonies (less than 2/100 mL). The maximum total and fecal coliform level found in the water were 21 and 10 coliform per 100 mL, respectively. Maximum fecal Streptococcus was 425/100 mL in the sample from 15 metres at the upper lake site near the Bosporus (site 4). However, the next highest fecal Streptococcus count was 16/100 mL. This one high Streptococcus value probably reflects the

effect of fecal pollution from animals, either a bird or mammal, as there were no obvious human sources of pollution, and because the coliform levels in the same sample were low (2/100 mL). There was little or no difference in bacteria indicators between the upper and middle lakes. The single sample collected from the Lower Waterton Lake (site 10) in September had higher colony counts for all three indicators than the majority of other samples, suggesting reduced bacterial quality at this site. A number of factors may have contributed to this situation. The sample was collected in the shallow water immediately below the Dardanelles. As a result the sample was more susceptible to surface runoff and mixing of bottom sediment than the other sites. This may have been of particular significance during the September sampling period due to heavy rainfall the night before collection of the samples. The pit toilets in the nearby picnic site may also have been a factor.

The bacteriological data show that coliform density are within recommended guidelines (CCREM, 1987) for all likely uses except as drinking water for which the maxmium acceptable total coliform concentration is 10/100 mL (National Health and Welfare, 1987). This level was exceeded in only 1 of 32 samples from the mid-lake sites. This is not of particular concern as some form of disinfection should always be used before drinking surface waters.

Comparison of the 1988 bacteria data with data from the

1970s show the indicator bacteria levels at the sites closest to the townsite sites 2 and 3 'south of Waterton' and 'at Waterton' have declined. During the 1970s the levels ranged as high as 1100/100 mL total coliform and were greater than 40/100 mL in more than 30 percent of samples from these sites. However, care must be taken when comparing the data as two different analytical methods were used in 1974 and 1975. In 1974, the most probable number (MPN) method was used. In 1975 the membrane filtration (MF) method replaced the MPN method and has been used by the Water Quality Branch since then. The 1974 results using MPN were higher than 1975 results for the same sites using the MF technique. However, 1975 results for site 'south of Waterton' was still higher than those found in 1988 using the same method. This apparent improvement in bacteria levels in the vicinity of the Waterton townsite is probably due to the improvement in sewage treatment practices and the discontinuation of sewage discharge into Cameron Creek in 1976.

3.1.3 Nutrient Parameters

The plant nutrient data (Table 5) show that concentrations of phosphorus, nitrogen and carbon are all very low. Phosphorus was for the most part below the analytical detection limit of 0.003 mg/L, although phosphorus at low levels (0.003 to 0.007 mg/L) was found in the Middle and Lower Waterton lakes in September. Total nitrogen concentrations ranged from 0.10 to 0.17 mg/L. At the upper lake sites, most

Table 5. Nutrient Data for the Mid Lake Sites, 1988.

Site No.	Collection Date	TP 15406L	DP 15103D	DOC 06104L	TOC 06002L	POC 06901L	DN 07651L	PN 07901L	TN 07603L	NO2 NO3 07110D
1	08/16	< 0.003	< 0.003	0.783	0.88	0.097	0.136	0.015	0.15	0.134
1	08/16	0.003	< 0.003	0.859	0.98	0.120	0.136	0.017	0.15	0.098
1	09/20	0.003	< 0.003	0.975	1.1	0.120	0.128	0.012	0.14	0.096
1	09/20	< 0.003	< 0.003	0.872	0.97	0.095	0.119	0.010	0.13	0.097
2	08/16	< 0.003	< 0.003	0.729	0.82	0.094	0.133	0.013	0.16	0.101
2	08/16	0.003	< 0.003	0.743	0.85	0.107	0.138	0.010	0.15	0.107
2	09/20	< 0.003	< 0.003	0.864	0.99	0.128	0.117	0.015	0.13	0.098
2	09/20	< 0.003	< 0.003	0.873	0.98	0.105	0.119	0.013	0.13	0.099
3	08/16	< 0.003	< 0.003	0.752	0.85	0.103	0.136	0.017	0.15	0.102
3	08/16	< 0.003	< 0.003	0.681	0.78	0.097	0.153	0.016	0.17	0.104
3	09/20	< 0.003	< 0.003	0.880	1.00	0.117	0.123	0.015	0.14	0.096
3	09/20	< 0.003	< 0.003	0.843	0.96	0.117	0.132	0.017	0.15	0.111
4	08/16	< 0.003	< 0.003	0.796	0.89	0.098	0.147	0.015	0.16	0.103
4	08/16	< 0.003	< 0.003	0.841	1.09	0.245	0.131	0.032	0.16	0.107
4	09/20	< 0.003	< 0.003	0.935	1.03	0.098	0.122	0.012	0.13	0.098
4	09/20	< 0.003	< 0.003	0.821	0.9	0.082	0.118	0.012	0.13	0.097
5	08/16	< 0.003	< 0.003	1.00	1.14	0.144	0.116	0.022	0.14	0.078
5	08/16	< 0.003	< 0.003	0.942	1.09	0.145	0.121	0.021	0.14	0.078
5	09/20	0.004	< 0.003	0.978	1.28	0.304	0.055	0.048	0.10	0.024
5	09/20	0.004	< 0.003	0.956	1.27	0.315	0.066	0.047	0.11	0.024
6	08/16	< 0.003	< 0.003	0.840	1.01	0.166	0.113	0.027	0.14	0.080
6	09/20	0.007	< 0.003	0.981	1.28	0.294	0.064	0.045	0.11	0.024
7	08/16	< 0.003	< 0.003	0.869	1.02	0.154	0.116	0.022	0.14	0.076
7	09/20	0.005	< 0.003	1.06	1.39	0.334	0.055	0.047	0.10	0.023
8	08/16	< 0.003	< 0.003	0.877	1.02	0.144	0.121	0.021	0.14	0.083
8	08/16	< 0.003	< 0.003	0.870	1.01	0.138	0.110	0.022	0.13	0.076
8	09/20	0.005	< 0.003	1.01	1.29	0.275	0.063	0.043	0.11	0.025
8	09/20	0.005	< 0.003	0.970	1.33	0.356	0.063	0.050	0.11	0.024
9	08/16	0.003	< 0.003	0.950	1.10	0.149	0.124	0.022	0.14	0.073
9	09/20	< 0.003	< 0.003	0.979	1.29	0.312	0.059	0.038	0.10	0.024
10	08/18	0.003	< 0.003	1.02	1.17	0.147	0.110	0.022	0.13	0.072
10	09/21	0.004	< 0.003	0.992	1.33	0.333	0.063	0.046	0.11	0.024

Data in mg/L unless stated otherwise.

of this nitrogen was in a dissolved nitrate/nitrite form. In the middle and lower lakes, nitrogen concentrations were comparable with the upper lake sites during August. In September, however, total nitrogen concentrations declined by about 25 percent, and a smaller proportion of the nitrogen was in the dissolved form and nitrate/nitrite represented less than half of the dissolved nitrogen. Organic carbon concentrations ranged from 0.78 to 1.39 mg/L. As with phosphorus and nitrogen, organic carbon levels were stable in the upper lake samples. At the middle and lower lake sites the organic carbon concentrations were slightly higher and a greater portion was particulate organic carbon, particularly in the September samples when total organic carbon levels were higher. These low levels of plant nutrients result in only limited algal growth throughout the lakes as seen in the low (0.001 to 0.006 mg/L) chlorophyll a levels.

The trophic status of lakes may range from oligotrophic to eutrophic. The general characteristics of oligotrophic lakes include: low nutrient concentrations, low algal biomass, minimal aquatic plant growth, low fish productivity, minimal oxygen depletion, high water clarity, and largely inorganic sediments. Oligotrophic lakes are considered to have very 'good' water quality conditions, and no impairment of uses. The trophic status of a lake is usually characterized by mean phytoplankton biomass (chlorophyll a), the level of the primary nutrient limiting plant growth (phosphorus), water clarity (secchi depth), and rate of

depletion of oxygen. Comparison of these indicators in the Waterton Lakes with trophic state probabilities associated with each as defined by Vollenweider and Kerekes (1980) for lakes throughout the world are presented in Table 6. This comparison shows that the Waterton Lakes fall within the ultra-oligotrophic to mesotrophic classification.

Table 6. Most Probable Trophic Status of Waterton Lakes.

	Mean Phosphorus (mg/L)	Mean Chlorophyll a (mg/L)	Mean Secchi Depth (m)
Upper Waterton Lake	< 0.003	0.001	7.0
% ultra oligotrophic	> 57	13	22
% oligotrophic	< 40	59	40
% mesotrophic	< 3	28	33
% eutrophic		--	5
Middle Waterton Lake	0.003	0.003	4.6
% ultra oligotrophic	57	1	3
% oligotrophic	40	26	25
% mesotrophic	3	61	53
% eutrophic		12	19
Lower Waterton Lake	0.003	0.002	---
% ultra oligotrophic	57	5	
% oligotrophic	40	40	
% mesotrophic	3	50	
% eutrophic		5	

Probabilities are based data from Vollenweider and Kerekes (1981).

Comparison of the 1988 nutrient data with the data collected in 1974-75 show there has been little if any change. The phosphorus levels continue to be below detection in the upper lake. In the middle and lower lakes the phosphorus

concentrations, as noted above, are slightly higher. The maximum concentration in 1988 was 0.007 mg/L. This is comparable to the 1970s when the maximum concentration at these sites was 0.055 mg/L, however, the median of the 51 samples was 0.004 mg/L and only 5 results were greater than 0.010 mg/L. Nitrogen and carbon in 1988 were within or below the range of concentrations found in the 1970s (Figure 5).

3.1.4 Major Ions

The results of the major ion analyses are presented in Table 7. These data show that these waters are relatively soft with hardness levels ranging from 67.0 to 86.3 mg/L. The dominant cations and anions are calcium and bicarbonate reflecting the geology of the area which is predominately sedimentary deposits including dolomites and limestone.

The ion concentrations were generally consistent throughout the three lakes. However, the September sample from the lower lake (site 10) did display slightly higher calcium and bicarbonate levels (22.2 and 99.6 mg/L, respectively) than other samples collected in September and August at this site. This slight increase may, as noted in a previous section, reflect the influence of local surface runoff following heavy rains prior to sample collection as a result of the shallow nature of the site and its proximity to the Dardanelles.

Comparison of the 1988 major ion data with the 1974-75

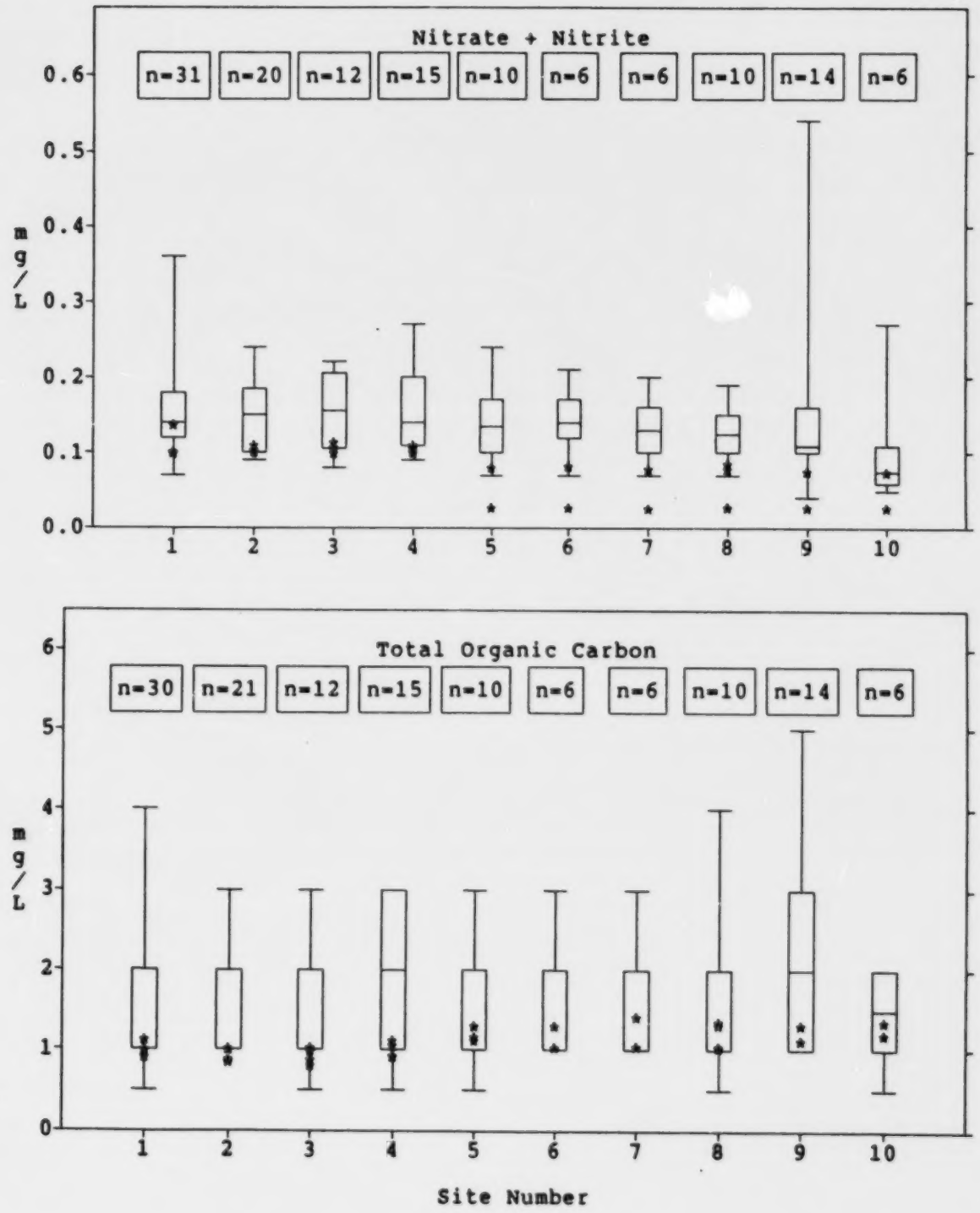

Figure 5. Box and Whisker Plots of Historical Nitrate/Nitrite and Total Organic Carbon Data with 1988 Data Overplotted. Where the box represents the quartiles, the line inside the box is the mean and the lines outside the box represent the range.

Table 7. Major Ion Data for the Mid Lake Sites, 1988.

Site No.	Collection Date	Fl 09106L	Na 11103L	Mg 12102L	SiO4 14102L	SO4 16306L	Cl 17206L	K 19103L	Ca 20103L	T ALK 10111L	Hardness 10602L	TDS 00201L	HCO3 06201L
1	08/16	0.02	0.70	6.8	2.31	2.7	0.2	0.22	20.1	76.4	78.2	79.	93.1
1	08/16	0.02	0.62	6.0	2.09	2.2	0.1	0.21	18.1	68.5	69.9	71.	83.5
1	09/20	0.02	0.60	5.6	1.92	3.3	0.3	0.19	18.1	67.8	68.3	71.	82.6
1	09/20	0.02	0.58	5.6	2.03	2.9	0.3	0.19	18.0	66.	68.	70.	80.5
2	08/16	0.02	0.60	6.1	2.15	2.2	0.1	0.18	18.7	65.1	71.8	70.	79.4
2	08/16	0.01	0.54	5.5	1.92	1.9	0.2	0.18	17.3	66.1	65.8	68.	80.6
2	09/20	0.02	0.56	5.6	1.92	3.1	0.3	0.17	18.2	62.6	68.5	68.	76.3
2	09/20	0.02	0.58	5.6	1.95	3.	0.4	0.19	18.3	64.4	68.8	69.	78.5
3	08/16	0.01	0.54	5.5	2.05	2.	0.2	0.17	17.5	63.7	66.3	67.	77.7
3	08/16	0.01	0.54	5.5	1.95	2.	0.2	0.17	17.4	62.5	66.1	66.	76.2
3	09/20	0.02	0.56	5.6	1.94	2.9	0.2	0.18	18.0	64.2	68.	68.	78.2
3	09/20	0.02	0.56	5.6	1.99	3.3	0.3	0.18	18.0	64.3	68.	69.	78.4
4	08/16	0.02	0.58	6.0	2.11	2.3	0.2	0.20	18.6	68.6	71.1	72.	83.6
4	08/16	0.02	0.60	6.1	2.11	2.2	0.2	0.19	18.6	65.6	71.6	70.	80.0
4	09/20	0.02	0.56	5.5	1.90	3.3	0.3	0.18	18.1	64.7	67.8	69.	78.9
4	09/20	0.02	0.56	5.6	1.91	3.1	0.3	0.18	18.2	65.6	68.5	70.	80.0
5	08/16	0.02	0.54	5.5	2.04	2.1	0.3	0.18	17.7	65.2	66.8	68.	79.5
5	08/16	0.02	0.60	6.0	2.10	2.2	0.2	0.20	18.6	67.6	71.1	71.	82.4
5	09/20	0.02	0.64	6.2	1.61	3.3	0.3	0.21	19.0	70.1	73.	73.	85.5
5	09/20	0.02	0.64	6.3	1.75	3.5	0.3	0.26	19.4	67.9	74.4	73.	82.8
6	08/16	0.02	0.56	5.6	1.94	2.2	0.2	0.18	17.6	67.3	67.0	69.	82.0
6	09/20	0.02	0.62	6.2	1.68	3.4	0.4	0.19	19.1	70.1	73.2	74.	85.5
7	08/16	0.01	0.54	5.6	1.93	2.	0.2	0.18	17.6	66.3	67.0	68.	80.8
7	09/20	0.02	0.62	6.2	1.65	3.	0.5	0.21	18.8	69.1	72.5	73.	84.2
8	08/16	0.01	0.54	5.6	1.96	2.2	0.2	0.18	17.7	63.6	67.3	67.	77.5
8	08/16	0.01	0.56	5.6	1.92	2.2	0.3	0.18	17.6	63.6	67.0	67.	77.5
8	09/20	0.02	0.30	6.4	1.73	3.5	0.4	0.23	19.4	71.7	74.8	75.	87.4
8	09/20	0.02	0.62	6.3	1.82	3.2	0.3	0.19	19.7	68.2	75.1	73.	83.1
9	08/16	0.01	0.58	6.0	2.21	2.3	0.2	0.20	18.3	67.0	70.4	70.	81.7
9	09/20	0.02	0.64	6.2	1.72	3.3	0.3	0.21	18.9	69.3	72.7	73.	84.5
10	08/18	0.02	0.60	6.0	2.09	2.3	0.2	0.20	18.4	69.5	70.6	72.	84.7
10	09/21	0.02	0.75	7.5	2.09	4.3	0.4	0.23	22.2	81.7	86.3	87.	99.6

Data in mg/L unless stated otherwise

data shows once again there has been no significant change between the two sampling periods. Figures 6 and 7 present graphic illustration of this with the 1988 data generally falling within the range of values reported in the 1970s for calcium, sodium, chloride and sulphate.

3.1.4 Metals

Based on results of earlier work and the routine monitoring in the Waterton River, metals were not expected to be a major concern. As a result, in the design of the study it was decided to collect metal samples only in August.

The results of the metals analyses (Table 8) did in fact confirm metals are not of concern in the Waterton Lakes. Only arsenic, barium, copper, and zinc were consistently detected and only at very low levels. The other metals examined were for the most part below detection. The levels of metals found are all at the lower end of the normal range of environmental concentrations (CCREM, 1987) and are considered to be natural levels.

3.2 Waterton Lakes Near Shore Program.

Examination of the near shore data (Table 9) shows very little difference in the nutrient, physical and biological results between the near shore sites and the mid-lake sites. However, sites 13 and 17, 'off Beach in Front of First Cabin' and 'at Warden's Dock', did have higher major ion levels

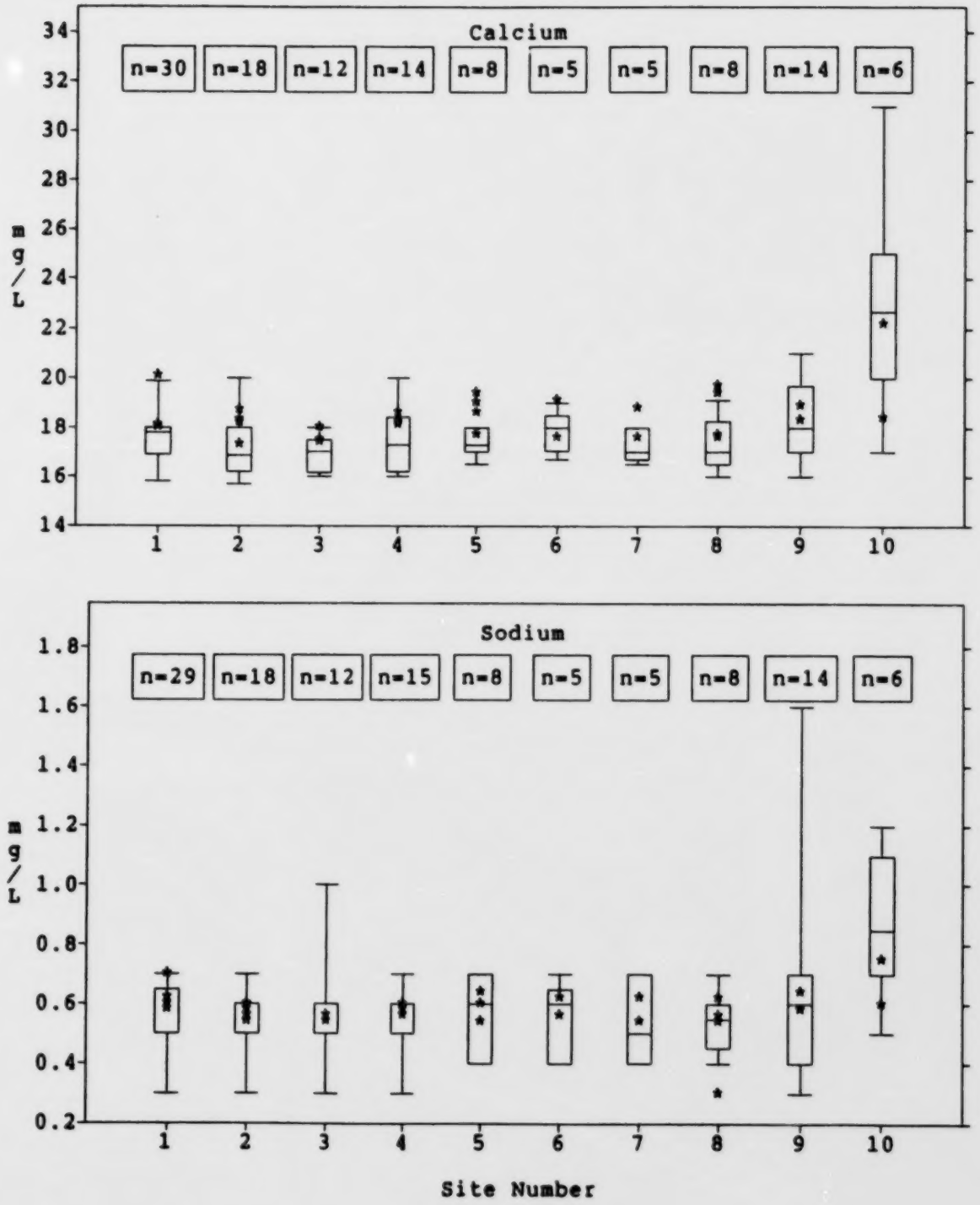

Figure 6. Box and Whisker Plots of Historical Calcium and Sodium Data with 1988 Data Overplotted. Where the box represents the quartiles, the line inside the box is the mean and the lines outside the box represent the range.

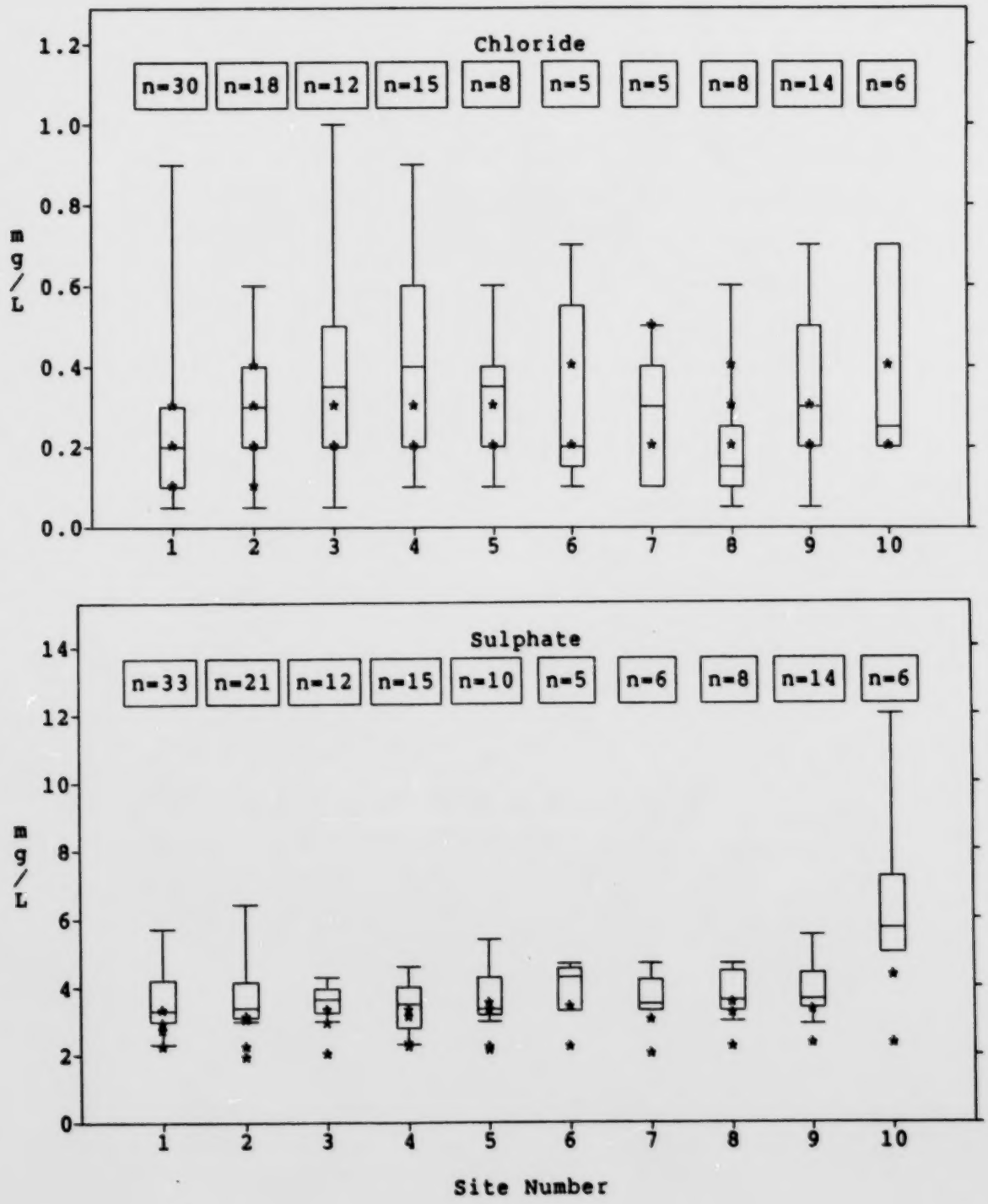

Figure 7. Box and Whisker Plots of Historical Chloride and Sulphate Data with 1988 Data Overplotted. Where the box represents the quartiles, the line inside the box is the mean and the lines outside the box represent the range.

Table 8. Metal Data for the Mid Lake Sites, August, 1988.

Site No. (depth)	Ni (T) 28002P (ug/L)	Ba (T) 56001P (mg/L)	V (T) 23002P (ug/L)	Cu (T) 29005P (ug/L)	Zn (T) 30005P (ug/L)	Co (T) 27002P (ug/L)	Cd (T) 48002P (ug/L)	Hg (T) 80011P (ug/L)	Pb (T) 82002P (ug/L)	Fe (D) 26104G (mg/L)	Mn (D) 25104G (mg/L)	Al (D) 13102G (mg/L)	Se (D) 34108D (ug/L)	As (D) 33106D (ug/L)
1 (5)	< 0.5	0.133	< 0.5	0.8	0.6	< 0.5	< 0.1	< 0.01	< 0.7	0.008	0.009	< 0.1	< 0.1	0.2
1 (25)	< 0.5	0.100	< 0.5	1.0	1.8	< 0.5	< 0.1	< 0.01	< 0.7	0.009	< 0.002	< 0.1	< 0.1	0.2
2 (5)	< 0.5	0.111	< 0.5	0.6	1.0	< 0.5	< 0.1	< 0.01	< 0.7	0.017	0.003	< 0.1	< 0.1	0.2
2 (25)	< 0.5	0.111	< 0.5	0.9	1.4	< 0.5	< 0.1	< 0.01	< 0.7	< 0.007	0.004	< 0.1	< 0.1	0.2
3 (5)	< 0.5	0.100	< 0.5	< 0.5	0.8	< 0.5	< 0.1	< 0.01	< 0.7	< 0.007	< 0.002	< 0.1	< 0.1	0.2
3 (25)	< 0.5	0.100	< 0.5	< 0.5	0.5	< 0.5	< 0.1	< 0.01	< 0.7	0.012	< 0.002	< 0.1	< 0.1	0.2
4 (5)	< 0.5	0.100	< 0.5	0.5	0.9	< 0.5	< 0.1	< 0.01	< 0.7	< 0.007	0.003	< 0.1	< 0.1	0.2
4 (25)	< 0.5	< 0.08	< 0.5	0.5	0.8	< 0.5	< 0.1	< 0.01	< 0.7	0.016	0.006	< 0.1	< 0.1	0.2
5 (5)	< 0.5	0.089	0.8	0.7	0.8	< 0.5	< 0.1	< 0.01	< 0.7	< 0.007	< 0.002	< 0.1	< 0.1	0.2
5 (15)	< 0.5	0.089	< 0.5	0.6	0.6	< 0.5	< 0.1	< 0.01	< 0.7	0.016	0.003	< 0.1	< 0.1	0.2
6 (4)	< 0.5	0.089	< 0.5	0.8	1.1	< 0.5	< 0.1	0.02	< 0.7	< 0.007	< 0.002	< 0.1	< 0.1	0.2
7 (5)	< 0.5	0.100	< 0.5	0.7	2.7	< 0.5	< 0.1	< 0.01	< 0.7	< 0.007	0.003	< 0.1	< 0.1	0.2
8 (5)	< 0.5	< 0.08	< 0.5	0.5	1.1	< 0.5	< 0.1	< 0.01	< 0.7	0.011	< 0.002	< 0.1	NV	NV
8 (20)	< 0.5	0.089	< 0.5	NV	NV	< 0.5	0.1	< 0.01	< 0.7	< 0.007	< 0.002	< 0.1	< 0.1	0.2
9 (1)	< 0.5	0.100	< 0.5	0.6	0.7	< 0.5	< 0.1	< 0.01	< 0.7	0.009	0.003	< 0.1	< 0.1	0.2
10 (1)	< 0.5	< 0.08	< 0.5	0.5	1.0	< 0.5	< 0.1	< 0.01	< 0.7	0.015	< 0.002	< 0.1	< 0.1	0.2

Table 9. Water Quality Data for Near Shore Sampling Sites, August 1988.

Site No.	Depth 97251F metres	Colour 02021L r.unit	NFR 10401L	Cond 02041F usie/cm	Temp 02061L deg C	DO 08101W	Turb 02073L NTU	pH 10301L pH unit	Ch-a 06717G	TC (MF) 36002F -----	FC (MF) 36012F #/100 mL	FS (MF) 36103F -----
11	1.0	< 5.	< 1.0	137.	12.5	10.1	0.24	8.22	0.001	4.	4.	26.
12	1.0	< 5.	< 1.0	139.	14.5	9.3	0.17	8.21	0.001	4.	< 2.	2.
13	1.0	< 5.	< 1.0	167.	14.5	9.8	0.31	8.27	< 0.001	< 2.	< 2.	18.
14	1.0	< 5.	< 1.0	141.	14.6	10.	0.17	8.20	< 0.001	< 2.	< 2.	< 2.
15	1.0	< 5.	< 1.0	137.	14.5	9.1	0.23	8.23	< 0.001	< 2.	< 2.	< 2.
16	1.0	< 5.	< 1.0	137.	15.1	9.5	0.22	8.19	0.001	< 2.	< 2.	10.
17	1.0	< 5.	< 1.0	166.	14.8	9.0	0.38	8.29	< 0.001	10.	10.	2.
18	1.0	< 5.	1.0	141.	14.6		0.52	8.20	0.001	< 2.	< 2.	10.
19	1.0	< 5.	1.0	144.	15.6	8.8	0.63	8.19	< 0.001	< 2.	< 2.	< 2.
20	1.0	< 5.	1.0	137.	15.9	9.0	0.41	8.20	0.001	4.	< 2.	2.

Site No.	F 09106L	Na 11103L	Mg 12102L	SiO4 14102L	SO4 16306L	Cl 17206L	K 19103L	Ca 20103L	T ALK 10111L	Hardness 10602L	TDS 00201L	HCO3 06201L
11	0.02	0.56	5.6	1.95	2.2	0.2	0.18	17.8	67.8	67.5	70.	82.6
12	0.02	0.56	5.8	1.96	2.3	0.2	0.18	17.9	68.2	68.6	70.	83.1
13	0.03	0.77	7.5	2.37	2.4	0.4	0.24	21.3	83.2	84.1	85.	101.4
14	0.02	0.56	5.8	1.97	2.1	0.3	0.20	17.9	68.8	68.6	71.	83.9
15	0.02	0.54	5.6	1.92	2.	0.3	0.18	17.9	67.3	67.8	69.	82.0
16	0.02	0.54	5.5	1.92	2.2	0.2	0.18	17.5	67.0	66.3	69.	81.7
17	0.03	0.77	7.5	2.34	2.7	0.3	0.25	21.0	83.0	83.3	85.	101.2
18	0.02	0.56	5.9	1.95	2.	0.4	0.18	17.9	68.5	69.	71.	83.5
19	0.02	0.60	6.0	2.06	1.9	0.4	0.19	18.4	70.9	70.6	72.	86.4
20	0.02	0.54	5.4	1.89	1.8	0.4	0.17	17.1	66.6	64.9	68.	81.2

Site No.	TP 15406L	DP 15103D	DOC 06104L	TOC 06002L	POC 06901LD	DN 07651L	PN 07901L	TN 07603L	NO2 NO3 07110D
11	< 0.003	< 0.003	0.850	0.95	0.104	0.112	0.014	0.13	0.094
12	< 0.003	< 0.003	0.857	0.95	0.096	0.130	0.015	0.15	0.103
13	< 0.003	< 0.003	0.850	0.97	0.119	0.140	0.016	0.16	0.103
14	< 0.003	< 0.003	0.926	1.01	0.086	0.128	< 0.01	0.14	0.103
15	0.003	0.003	0.840	0.91	0.067	0.138	< 0.01	0.15	0.111
16	0.003	< 0.003	0.890	0.99	0.100	0.129	0.014	0.14	0.116
17	0.003	0.003	0.881	0.97	0.089	0.134	< 0.01	0.14	0.111
18	0.003	< 0.003	0.884	0.97	0.084	0.134	< 0.01	0.14	0.111
19	0.003	< 0.003	0.977	1.12	0.146	0.122	0.015	0.14	0.082
20	0.003	< 0.003	1.04	1.2	0.155	0.106	0.022	0.13	0.084

Data in mg/L unless stated otherwise.

relative to the other near shore sites and the mid-lake sites. The increase was approximately 25 precent and was evident in the specific conductance and all the major ions except chloride. The cause of the increase is unknown at this time. Possible causes for these higher ion concentrations include groundwater inputs, storm sewage discharges and increased influence of surface runoff. Storm sewage discharges occur near both of these sites.

The likelihood of increased ion concentration due to any of these causes is greater at the Warden's dock (site 17). This site is located at the west end of Emerald Bay at the farthest point from the main lake. It is isolated from the main lake by a number of shoals near the mouth of the bay. As a result the flushing and mixing rates may be reduced in this bay. Other sites in Emerald Bay (site 15, 16 and 18) did not reflect this higher ion content but two of these sites, (15 and 16) are outside the shoals and therefore more likely to mix with the main lake. Site 18, although inside the shoals, is on the north side of Emerald Bay and more exposed to wind action from the main lake and would probably experience more mixing with the main lake than water off the Warden's dock. Site 13 is not isolated from the main lake and mixing of any input should occur rapidly.

3.3 Waterton River Site Evaluation

Routine monthly water samples are collected from the

Waterton River at Highway 6. The data generated by the monitoring have been seen to address a number of objectives including: providing information on the water quality in the river as it leaves the Park, and an indication of water quality conditions in the Waterton Lakes and at the International Boundary. However, the ability of these monitoring data to fulfill these objectives have not been demonstrated. Therefore, samples were collected to address this issue in conjunction with the lake studies in 1988.

3.3.1 To Assess Water Quality Leaving the Park

In order to determine the usefulness of the routine monitoring data from the 'Waterton River at Highway 6' to assess the quality of water leaving Waterton Lakes National Park, samples were collected at a total of five sites on Waterton River and Crooked Creek. The water quality data from the sampling program in 1988 is presented in Table 10. The data show that the quality of water in Waterton River is better than the quality of Crooked Creek. Comparison of results from the two streams shows that the levels of almost all the parameters tested (physicals, major ions and nutrients) in Crooked Creek were at least twice as high as in the Waterton River above Crooked Creek. The bacteriological indicator levels were as much as 10 times higher in Crooked Creek.

Water quality in Crooked Creek at Highway 5, during the

Table 10. Water Quality Data for the Waterton River ... Evaluation, 1988.

Site No.	Collection Date	Colour 02021L r. unit	NFR 10401L	Cond 02041L usie/cm	Temp 02061F deg C	DO 08101W	Turb 02081L NTU	pH 10301L pH unit	Ch-a 06717G	TC (MF) 36002F	FC (MF) 36012F	FS (MF) 36103F
										----- #/100 mL -----		
21	08/18	< 5.	< 1.	154.		8.8	0.45	8.23	0.001	16.	8.	40.
21	09/21	< 5.	2.2	180.	7.4	10.	1.86	8.13	0.003	22.	< 2.	6.
22	08/18	< 5.	< 1.	146.		9.2	0.71	8.18	0.001	17.	10.	30.
22	09/21	< 5.	< 1.	181.	7.7	10.	0.80	8.15	0.003	13.	6.	8.
23	08/18	< 5.	1.	175.		8.6	0.51	8.22	0.001	20.	12.	22.
23	09/21	< 5.	1.	190.	8.0	10.	1.20	8.15	0.003	140.	< 2.	210.
24	08/18	10.	11.	400.		8.0	9.6	8.17	< 0.001	900.	100.	390.
24	09/21	7.5	3.6	493.	7.7	9.8	4.3	8.21	< 0.001	130.	38.	90.
25	09/21	15.	2.4	499.	6.8	9.8	3.4	8.48	< 0.001	NV	46.	10.

Site No.	Collection Date	Fl 09106L	Na 11103L	Mg 12102L	SiO4 14102L	SO4 16306L	Cl 17206L	K 19103L	Ca 20103L	T ALK 10111L	Hardness 10602L	TDS 00201L	HCO3 06201L
21	08/18	0.03	0.70	6.4	2.41	3.5	0.2	0.20	19.2	74.1	74.3	77.	90.3
21	09/21	0.03	0.86	8.0	2.37	4.1	0.3	0.26	23.1	85.4	90.6	90.	104.1
22	08/18	0.02	0.60	6.0	2.10	2.2	0.1	0.20	18.5	70.6	70.9	72.	86.1
22	09/21	0.04	0.88	8.2	2.43	4.4	0.3	0.28	23.0	87.8	91.2	92.	107.0
23	08/18	0.03	0.89	8.2	2.55	2.9	0.4	0.25	21.7	88.5	87.9	90.	107.9
23	09/21	0.03	1.01	8.7	2.57	4.4	0.3	0.34	23.7	90.9	95.	96.	110.8
24	08/18	0.09	5.71	25.3	6.75	3.9	1.2	1.40	38.5	214.	200.3	211.	260.9
24	09/21	0.10	5.60	29.2	6.86	9.7	2.0	1.70	55.3	260.	258.3	267.	316.9
25	09/21	0.09	5.91	28.7	7.79	10.7	2.3	1.98	57.7	262.	262.2	272.	306.2

Site No.	Collection Date	TP 15406L	DP 15103D	DOC 06104L	TOC 06002L	POC 06901L	DN 07651L	PN 07901L	TN 07603L	NO2 NO3 07110D
21	08/18	0.003	< 0.003	1.06	1.2	0.141	0.068	0.022	0.09	0.037
21	09/21	0.005	< 0.003	1.29	1.57	0.280	0.054	0.036	0.09	< 0.01
22	08/18	0.004	< 0.003	1.15	1.29	0.138	0.065	0.021	0.09	0.022
22	09/21	0.003	< 0.003	1.27	1.49	0.215	0.052	0.030	0.08	< 0.01
23	08/18	0.004	< 0.003	1.31	1.45	0.135	0.065	0.015	0.08	0.023
23	09/21	0.022	0.003	1.34	1.55	0.209	0.055	0.030	0.09	< 0.01
24	08/18	0.014	0.004	3.99	4.46	0.474	0.164	0.050	0.21	< 0.01
24	09/21	0.010	< 0.003	3.91	4.13	0.221	0.146	0.027	0.17	< 0.01
25	09/21	0.010	< 0.003	4.60	4.78	0.177	0.183	0.022	0.21	< 0.01

Data in mg/L unless stated otherwise.

early 1970s was not as good as in Waterton River (Block and Gummer, 1976). A number of reasons account for this reduced water quality. Crooked Creek originates in Waterton Lakes National Park, but exits the Park and flows through a number of cattle ranches prior to re-entering the Park and discharging into the Waterton River. Much of the area drained by Crooked Creek is flat-topped silt, sand and gravel terraces, known as Kame Terraces. Numerous shallow water bodies occur throughout this area which drain into Crooked Creek. The characteristics of the drainage basin and the cattle ranching which occurs in the basin contribute to the inferior water quality in the creek. Groundwater input to the creek during low flow conditions may also contribute to the poorer quality.

The data from this study shows that Crooked Creek does affect the water quality in the Waterton Rvier, at least during low flow conditions. The data show increases in selected parameters ranging from 3 to 25 precent (Table 11). Unfortunately, flow data for Crooked Creek at the time of sample collection is not available to allow accurate calculation of dilution factors. However, historical flow data shows that mean monthly flow in Crooked Creek in August and September are 2.5 and 3.6 percent of the Waterton River flow (Water Resources Branch, 1985). If these historical flows are used as a basis to estimate dilution of Crooked Creek water in the Waterton River, the increase in concentration of the parameters presented in Table 11 would

range from 2.8 to 7.4 percent (eg. 7.4 percent increase in total organic carbon in September). This estimated increase is not greatly different from that found in the September samples but is substantially lower than the results for the August samples (Table 11). This discrepancy in the August results may be a reflection of inaccuracies in the flow estimates, or the Waterton River may not have been well mixed where the downstream sample was taken in August.

Table 11. Effect of Crooked Creek on Water Quality in Waterton River, 1988.

Collection Site	Specific Conductance (usie/cm)		Calcium (mg/L)		Bicarbonate (mg/L)		Total Organic Carbon (mg/L)	
	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.	Aug.	Sept.
Waterton R. Upstream	146	180	18.5	23.0	86.1	107.0	1.29	1.49
Crooked Cr.	400	493	38.5	55.3	260.9	316.0	4.46	4.13
Waterton R. Downstream	175	190	21.7	23.7	107.9	110.8	1.45	1.55
Change	29	10	2.2	0.7	21.8	3.8	0.16	0.06
% Change	19.9	5.5	11.8	3.0	25.3	3.6	12.4	4.0
Est. Change *	5.2	5.2	3.2	2.9	6.1	2.8	7.4	5.3

* Change estimated assuming Crooked Creek had 3 % of Waterton River flow at time of sampling

The seasonal sewage discharge from the Waterton sewage treatment plant which occurs between the routine monitoring site and the Park boundary is also of concern in terms of the water quality leaving the Park. The sewage lagoon discharge

is normally conducted during spring high flow when dilution is greatest. Elliott (1985) demonstrated that the sewage discharge had little or no measurable effect on the water quality in the Waterton River in 1985. Further assessment of the impact of the sewage discharge on Waterton River was not attempted as part of this study because there was no release during the study period. However, if discharges are made during low flow conditons, monitoring should be undertaken to assess the possible impacts on water quality in the Waterton River.

3.3.2 To Assess Waterton Lakes Water Quality

Comparsion of the routine monitoring data collected at the Waterton River at Highway 6 with the data collected in the Waterton Lakes was used to assess the usefulness of the river data to describe the water quality throughout the Waterton Lakes and at the International Boundary. Mean concentrations of eight selected parameters from the International Boundary site, the four Upper Waterton Lake sites, the six Middle and Lower Waterton Lake sites and all ten lake sites collected in the 1970s and in 1988 were compared to mean concentrations from the Waterton River site, collected during the same time period (Figures 8 to 11). These figures show that the mean concentration of these parameters in the Waterton River at Highway 6 are comparable to the Waterton Lake sites. In the case of specific conductance, calcium and sodium, the mean concentrations at the Waterton River site are higher than in

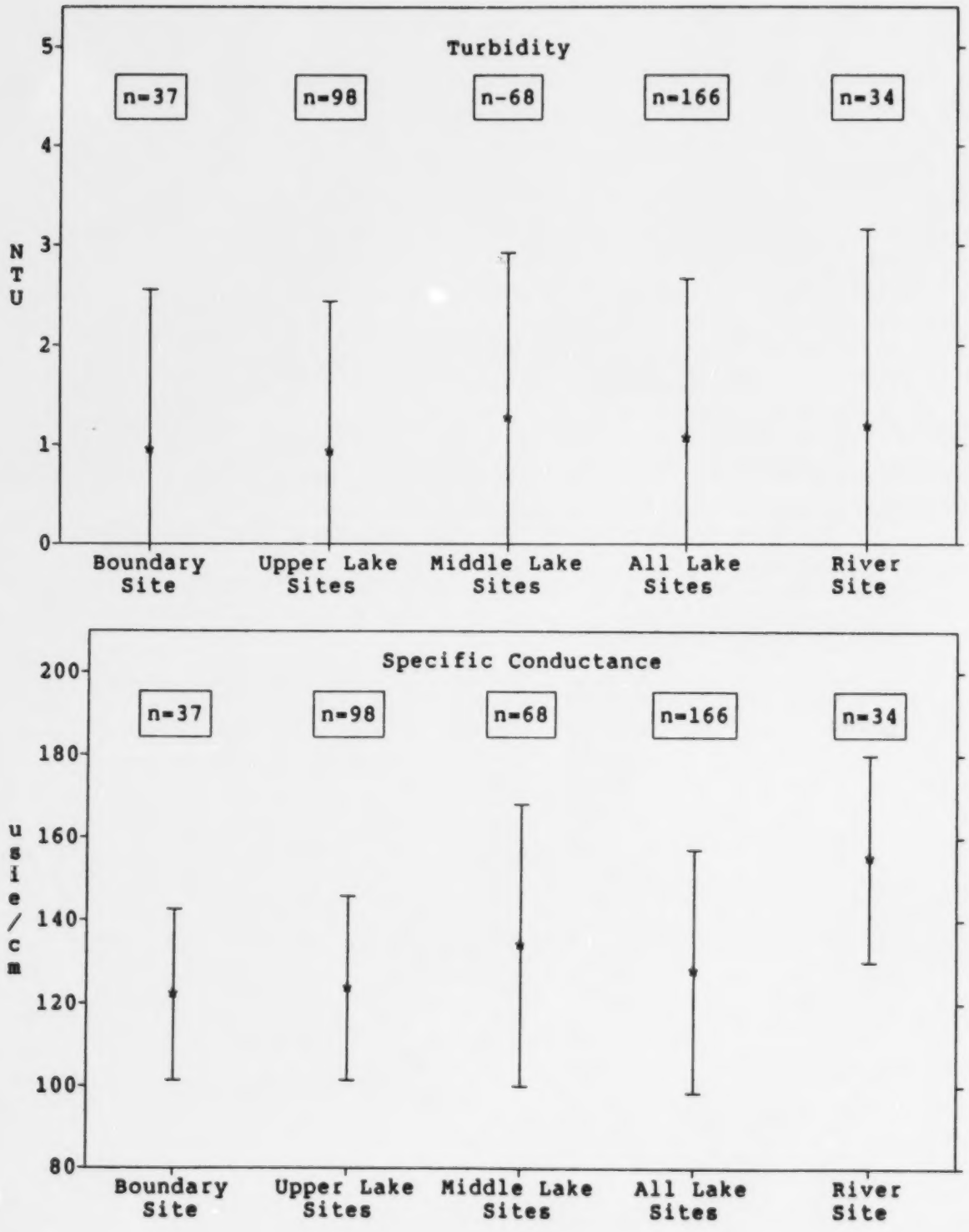

Figure 8. Plot of Mean Turbidity and Specific Conductance Levels at Waterton Lakes and River Sites.

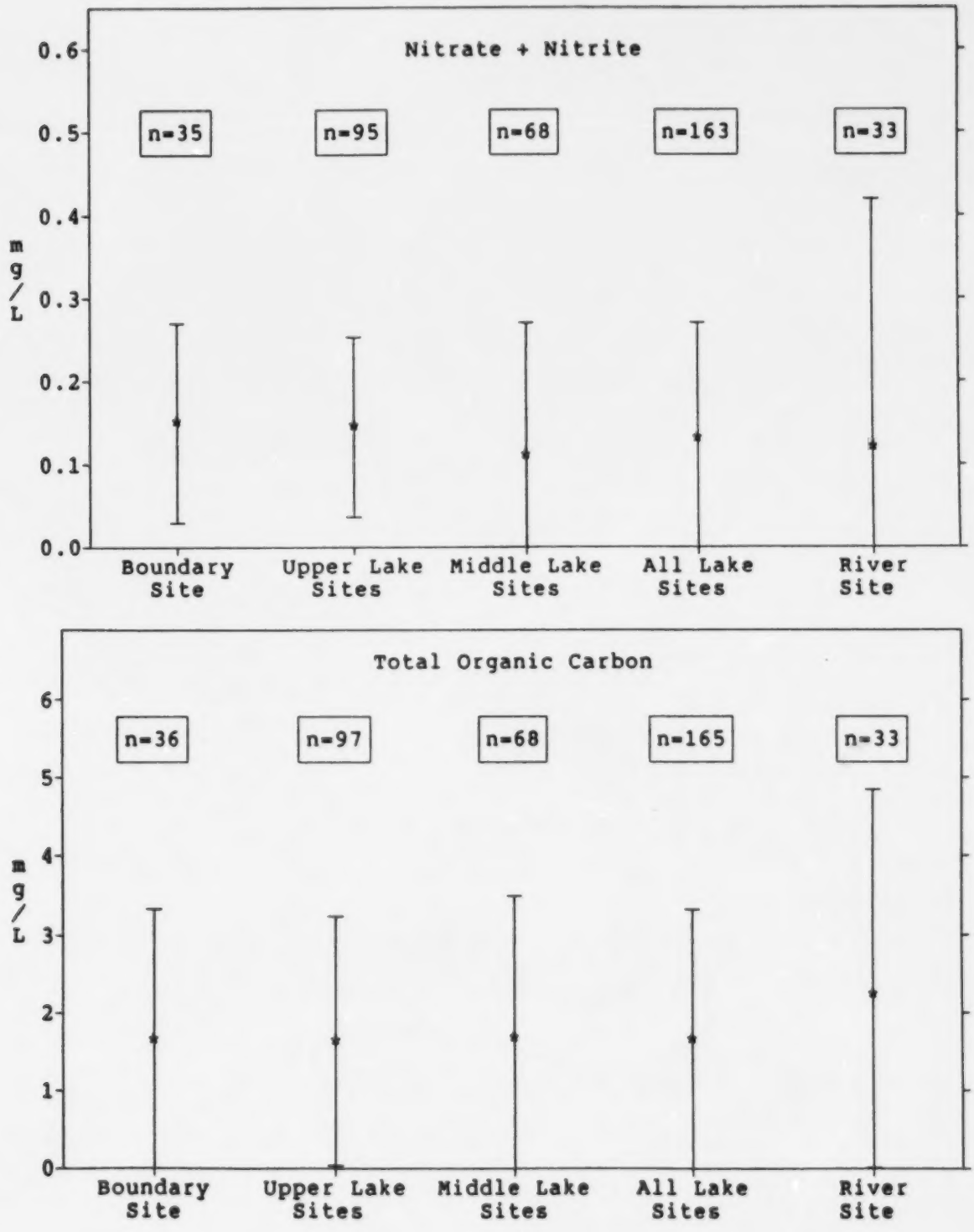

Figure 9. Plot of Mean Nitrate/Nitrite and Total Organic Carbon Concentrations at Waterton Lakes and River Sites.

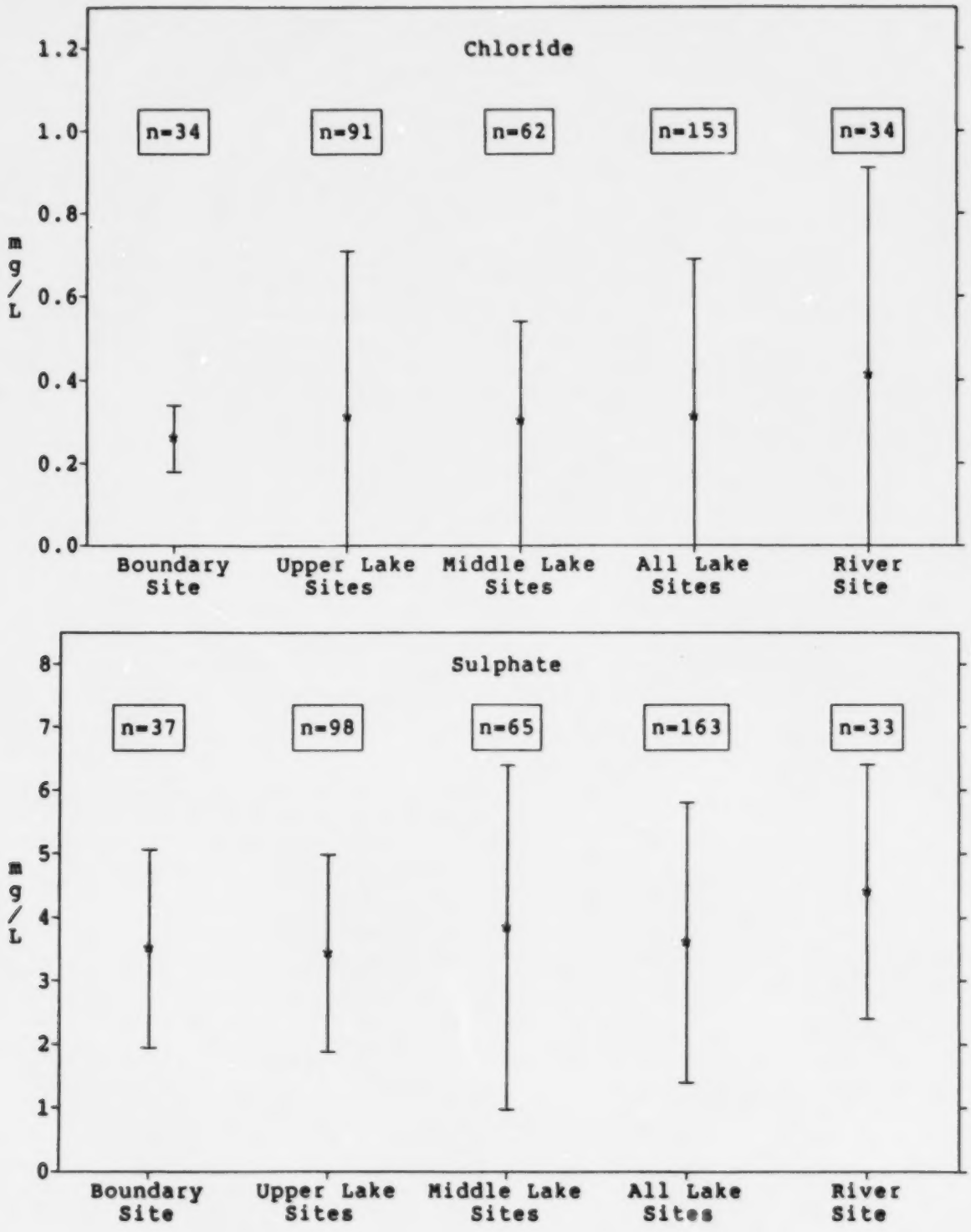

Figure 10. Plot of Mean Chloride and Sulphate Concentrations at Waterton Lakes and River Sites.

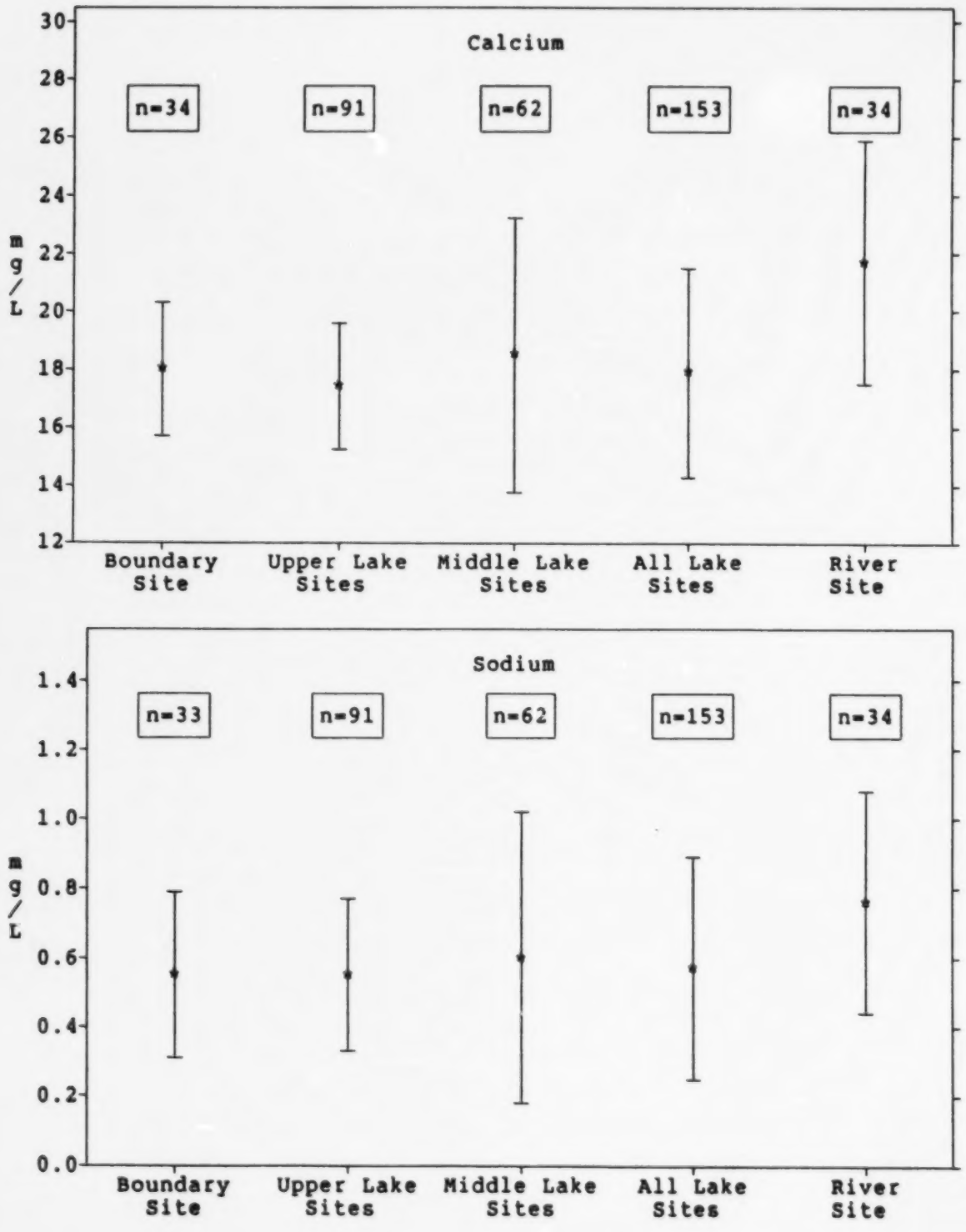

Figure 11. Plot of Mean Calcium and Sodium Concentrations at Waterton Lakes and River Sites.

the Waterton Lakes. However, the large overlap in the confidence intervals show there is no statistical difference between the river and the lake data.

The comparability of the data from the routine monitoring in the Waterton River with the lakes data indicates that the routine monitoring of Waterton River at Highway 6 gives a reasonable estimate of the water quality conditions in the lakes, including at the International Boundary. This finding is not particularly surprising considering the relatively consistent water quality found throughout the lakes and the lack of upstream development which could have an impact on the water quality. Using the Waterton River monitoring program to assess the water quality in the Waterton Lakes does have limitations. The volume of the Waterton Lakes relative to the normal outflow in the Waterton River suggest a flushing rate in the order of 1.25 years (lake volume/mean outflow). Therefore, any deterioration of the water quality in the upper reaches of the lakes might not be observed at the river site until well after it has occurred. To avoid this potential problem, any development in Glacier or Waterton Lakes National parks which might affect the water quality in the lake should be monitored to determine the local impacts. Periodic lake surveys similar to that conducted in 1988 should be conducted every five to ten years to ensure the monitoring results from the Waterton River continue to reflect conditions in the lakes.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The quality of water in the Waterton Lakes remains very high, with no apparent deterioration of quality since a similar study was conducted in 1974-75. The eutrophic classification of the Waterton lakes, based on phosphorus, chlorophyll a and transparency fall within the ultra-oligotrophic to mesotrophic range. Comparisons between the lakes show that the water in the Upper Waterton Lake is of marginally higher quality than the Middle and Lower Waterton lakes. This difference can probably be attributed to the physical difference in the lakes and the local inflow from the terrain surrounding the lakes which changes from mountainous in the upper to foothills in the lower reaches.

The near shore sampling program indicated that bacteria levels near Waterton townsite have declined since the survey conducted in the 1970s, probably due to improved sewage treatment and disposal. Bacteria counts at all the near shore sites were comparable to those found at the mid-lakes sites. All are at a level which is considered normal and probably of natural origin. One sample did have bacteria levels in excess of guidelines for drinking water, however, surface waters should not be advocated for drinking without disinfection.

Crooked Creek affects the Waterton River by causing an increase in major ion and nutrient concentrations at ranges from 3.5 to 25 percent. As a result, the monitoring of Waterton River at Highway 6 does not provide an accurate

indication of the quality of water leaving Waterton Lakes National Park. If the impact of Crooked Creek on the Waterton River is to be considered in assessing the quality of water leaving the Park, either the Waterton River site must be moved downstream of Crooked Creek or monitoring of Crooked Creek (including flow) must be undertaken to allow estimation of conditions leaving the Park. The impact of sewage discharges to the Waterton River on the quality of water leaving the Park was not assessed as there was no sewage discharge during the study period. Other studies have shown that the impact is minimal during high flow conditions. However, if sewage is discharged during low flow periods the impacts of these discharges should be assessed to determine their significance.

The water quality data generated at the routine monitoring site on the Waterton River at Highway 6 provides an indication of the water quality in the Waterton Lakes. However, if a deterioration of water quality were to occur in the upper reach of the lakes this impact would not likely be detected for a significant period of time due to the retention time in the lakes. Therefore, any new development in Glacier National Park or Waterton Lakes National Park which might affect the water quality of the lakes should be monitored. Periodic surveys of the Waterton lakes, similar to this study should be undertaken at a five to ten year interval to ensure the routine monitoring does continue to reflect conditions in the lakes.

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